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Engelmann Spruce Seed Production on the Fraser Experimental Forest, Colorado

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Two good, three heavy, and one bumper spruce seed crops were produced during a 10-year period. There was considerable variability in seed crops, however. Not all locations produced good to bumper seed crops every good or better seed year; conversely, some locations produced bumper seed crops in 2 or more years. Mathematical relationships were estimated between periodic annual 10-year sound seed production and (1) periodic annual 10-year total seed production, and (2) selected stand parameters of dominant and codominant spruces that should be useful in estimating potential sound seed production.

Keywords: *Picea engelmannii*, forest seed production

Management Implications

Knowledge of the frequency of good seed crops and the relationship of seed production to stand, tree and/or crown characteristics is essential to the management of spruce-fir forests when relying on natural reproduction. Dispersal and survival data from past studies indicate that enough viable seeds were produced in 6 out of 10 years of the current study to adequately restock all aspects under a group selection, individual tree selection, or shelterwood cutting alternative, provided that seedbed and environmental conditions are favorable, and the stand characteristics of the residual seed source are similar to the stands studied. Enough seeds were produced during the 10-year period to adequately regenerate all clearcut openings, except south aspects, if the openings were kept small enough (3- to 5-acre patches or strips no wider than 400 to 450 feet) to be within effective seed dispersal distances, seedbed and environmental conditions were favorable, and the stand characteristics of the trees surrounding the openings were similar to the seed source in the current study (Alexander 1974, 1977). Clearcutting on south slopes is not likely to result in successful natural spruce regeneration regardless of the quantity of seed available, even with good seedbeds, because of unfavorable environmental conditions (Noble and Alexander 1977).

Introduction

Prompt establishment of Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.) natural reproduction following timber harvest is a major objective in the management of spruce-subalpine fir [*Abies lasiocarpa* (Hook.) Nutt.) forests in the central and southern Rocky Mountains (Alexander 1974, 1977). Good seedbed conditions and a favorable environment are necessary requirements for natural reproduction, but they are of little value without an adequate seed supply (Noble and Alexander 1977, Roe et al. 1970). Infrequent good seed crops limit the potential for natural regeneration success and require either the use of cutting methods that provide a seed source on site or artificial reforestation (Alexander 1974, 1977; Ronco 1972).

Past studies of Engelmann spruce seedfall in the central and southern Rocky Mountains indicated that intervals between years of good to bumper seed production are erratic, with more poor than good seed crops

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(Alexander 1969, Jones 1967, Noble and Ronco 1978). Similar results have been reported for spruce seed production elsewhere (Alexander 1974).

A long-term study of spruce seed production, in high elevation forests, in central Colorado, was started in 1968; plots were established by 1970. A 5-year progress report was published (Alexander and Noble 1976). Those data are included here, along with the data for the years 1975 through 1979.

Study Areas

Thirteen permanent sample plots, 2-chains on a side, were established in old-growth spruce-fir forests, on the Fraser Experimental Forest (Alexander and Watkins 1977) (fig. 1). Plots covered a range of elevations, slopes, aspects, ages of dominant trees, and site productivity (table 1). All stands were in an *Abies lasiocarpa/Vaccinium scoparium* habitat type that were dominated by Engelmann spruce. Stand characteristics for each location are shown in table 2.

Methods

Seed Production

Seed production was estimated from seeds collected in 10 one-square-foot seed traps randomly located within each plot (fig. 2). Seed trap contents weere collected one or more times each fall beginning in mid- to late September, weather conditions permitting, and again the following spring. All seeds were tested for soundness and recorded as (1) filled, or (2) partially filled or empty. Estimates of total quantities of seed produced were based on counts of filled seed only.

Differences in seedfall for locations and years were tested by analysis of variance, with number of filled seeds per trap as the dependent variable. Because of non-homogeneity of the data, seed counts were transformed to $\sqrt{X + 3/8}$ to provide more stability to the variances.

Figure 1.—Engelmann spruce seed production study plot, Fraser Experimental Forest, Colo.

The following categories described by Alexander and Noble (1976) were used to rate the seed crops.

Filled seeds per acre	Seed crop rating
< 10,000	Failure
10,000–50,000	Poor
50,000–100,000	Fair
100,000–250,000	Good
250,000–500,000	Heavy
> 500,000	Bumper

Table 1.—Characteristics of plots in seed production study, Fraser Experimental Forest, Colorado

Plot number	Location	Elevation	Aspect	Slope	Site index	Average age dominants at breast height
		feet		*percent*		*years*
1	Deadhorse Creek	9,140	N45°E	5	58	292
2	Deadhorse Creek	9,120	N45°E	5	68	280
3	Fool Cr.	11,400	N25°E	5	42	250
4	Fool Cr.	10,820	N10°W	12	61	247
5	Fool Cr.	10,670	N10°E	15	50	242
6	Fool Cr.	10,000	N25°E	12	65	246
7	W. St. Louis Cr.	10,000	S50°E	25	70	289
8	W. St. Louis Cr.	9,520	Due E	5	78	283
9	W. St. Louis Cr.	9,560	Due N	30	64	291
10	Short Cr.	9,400	N15°E	18	66	269
11	Short Cr.	9,365	N50°W	13	77	246
12	E. St. Louis Cr.	9,800	S20°E	5	55	284
13	Main St. Louis Cr.	9,500	N10°W	5	82	192

Table 2.—Average stand characteristics, for dominant and codominant spruces, and total trees

Plot number	Trees		Basal area		Diameter		Height		Live crown	
	Spruce	Total	Spruce	Total	Spruce	Total	Spruce	Total	Spruce	Total
	number per acre		*square feet per acre*		*inches*		*feet*		*percent*	
1	65	320	84	150	15.4	9.3	78	50	74	68
2	55	250	100	174	18.1	11.3	88	58	67	66
3	88	220	133	190	16.7	12.6	60	47	71	70
4	103	323	196	307	18.7	13.2	80	59	64	61
5	95	525	91	255	13.2	9.4	66	50	58	54
6	63	345	101	194	17.2	10.2	85	55	63	60
7	65	365	106	204	17.3	10.1	87	52	67	65
8	65	288	126	213	18.8	11.7	94	59	62	62
9	90	278	102	180	14.4	10.7	84	63	54	55
10	43	283	58	142	15.8	9.6	86	54	65	65
11	35	213	69	138	19.0	10.9	99	56	73	70
12	63	293	77	179	15.0	10.6	79	57	70	67
13	73	203	142	198	18.9	13.4	97	68	65	65

The relationship between the amount of filled seed produced and total seefall was tested by regression analysis, with the number of filled seeds per trap as the dependent variable.

Stand, Tree, and Crown Characteristics

Stand inventory information was collected as a basis for relating seed production to some measure of stand density, and/or tree and crown characteristics. Information obtained for individual trees on the plots included:

1. Diameter at breast height to the nearest 0.1 inch (trees 3.6 inches d.b.h. and larger).
2. Total height to the nearest 0.5 foot.
3. Crown class.
4. Species.
5. Average length of live crown to the nearest 0.5 foot (average of four sides).
6. Average width of live crown to nearest 0.1 foot (average of two measurements).

Ages of six to eight dominant spruces were measured for determination of site index (Alexander 1967).

Figure 2.—One-foot square wire seed trap in place, Fraser Experimental Forest, Colo.

These data were used to compute the following stand, tree, and crown parameters:

1. Number of trees per acre.
2. Basal area per acre.
3. Crown competition factor per acre.
4. Total crown volume per acre.
5. Total crown surface area per acre.
6. Average growing space per acre.
7. Average spacing per acre.
8. Average diameter
9. Average height.
10. Average crown length.
11. Average crown width.
12. Average percent of live crown
13. Average crown width/diameter ratio.
14. Average height/crown width ratio.
15. Average crown volume.
16. Average crown surface area.

Estimated average annual seed production for each location was plotted against individual and combinations of stand, tree, and crown measures. A stepwise regression program was then used to select the set of independent variables best correlated with seed production. Parameters based only on dominant and codominant spruces were used, because numerous, studies have shown that coniferous species of these crown classes produce three-fourths or more of the seedfall (Fowells and Schubert 1956, Franklin et al. 1974).

Results and Discussion

Seed Production

Seed was produced in larger quantities and at more frequent intervals (table 3) than previously measured on the Fraser Experimental Forest (Alexander 1969) and elsewhere (Alexander 1974, Noble and Ronco 1978). Based on seed production averaged over all

Table 3.—Production of filled seeds (thousands per acre) and percent of total seedfall filled

Plot number	1970 Crop Filled seed	1970 Crop % of total	1971 Crop Filled seed	1971 Crop % of total	1972 Crop Filled seed	1972 Crop % of total	1973 Crop Filled seed	1973 Crop % of total	1974 Crop Filled seed	1974 Crop % of total	1975 Crop Filled seed	1975 Crop % of total	1976 Crop Filled seed	1976 Crop % of total	1977 Crop Filled seed	1977 Crop % of total	1978 Crop Filled seed	1978 Crop % of total	1979 Crop Filled seed	1979 Crop % of total	10-year average
1	148	43	44	17	131	24	13	15	209	48	174	67	26	38	673	62	135	48	4	10	151
2	680	50	139	26	231	26	17	13	340	52	348	64	26	40	1,398	66	218	44	13	25	341
3	531	47	200	21	366	24	52	15	109	21	100	40	4	4	1,407	63	61	33	4	6	284
4	558	36	152	31	436	32	4	1	362	33	344	53	35	16	1,616	67	65	24	17	17	359
5	544	47	96	23	292	28	17	10	422	33	204	55	26	23	1,359	64	35	24	13	21	301
6	292	42	161	21	266	27	13	13	436	43	226	50	9	29	910	49	87	36	4	12	240
7	218	36	170	23	179	24	30	25	274	33	113	52	0	0	924	60	57	35	9	14	197
8	366	44	191	30	431	32	35	25	222	40	140	49	9	33	1,316	64	78	43	22	33	281
9	362	40	335	23	357	24	9	15	244	38	144	52	22	33	1,734	68	109	37	35	42	335
10	104	33	148	24	170	32	9	10	122	36	148	60	0	0	405	60	65	21	4	12	118
11	83	29	253	38	57	18	9	6	109	37	109	69	13	38	196	54	52	35	4	33	88
12	401	48	61	14	270	32	17	13	135	38	166	42	26	35	736	66	39	29	9	12	186
13	161	30	754	25	470	18	22	11	540	47	296	50	4	10	1,885	65	248	41	22	15	437
Average	342	42	208	27	281	26	19	12	271	38	193	53	15	22	1,114	63	96	37	13	19	

locations, crops were rated as shown for the 10 years of observations:

Seed crop rating	Number of years
Failure	0
Poor	3
Fair	1
Good	2
Heavy	3
Bumper	1

There were differences in the quantity of seed produced from year to year. During the first 5 years of observation, good to heavy seed crops were produced in 4 out of 5 years; whereas, during the last 5 years, good to bumper crops were produced in only 2 years. Seed crops also varied considerably between locations. Not all locations produced good to bumper crops every good seed year, and some locations produced bumper crops in 2 or more years. Analysis of variance of the seed count data revealed that differences between years, locations, and the years times locations interaction were all highly significant ($p \leq 0.01$).

The amount of filled seed for each year at each location was significantly related to total seedfall, as shown in the following equation:

$$Y = 0.413\,X \tag{1}$$

$R^2 = 0.99$, $S_{y \cdot x} = 25{,}600$ (coefficient of determination not centered about the mean—zero-intercept model)

where
Y = number of filled seeds per acre
X = number of total seeds per acre.

The equation, which accounts for 99% of total variation in sound seed production, shows that the number of filled seed produced increases linearly with total seedfall (fig. 3). The large standard error of estimate also indicates considerable variability in the relationship between filled and total seed production between years and locations.

Another significant finding in this study is that despite good or better seed production in 6 years, an average of only 43% (range 26% to 63%) of the total seedfall collected were filled in those years. Seed loss to insects, in particular to the spruce seed worm (*Cydia youngana*), accounted for a large portion of the unsound partially filled seeds (Schmit et al. 1981).

The time of seedfall also varied between locations within any one year and between years at any location. The percentage of filled seed collected, by dates, is shown in table 4 for those years of significant seed production when weather conditions permitted collections in both the fall and the following spring. In 1971 and 1978, from 27% to 68% of the total sound seedfall collected was released by the end of September, while in 1972 the percentage of seed released by the end of September varied from 4% to 60%. By the middle of October 1972, however, 36% to 71% of the sound seeds collected had been dispersed. In 1974, 1975, and 1977, only nominal amounts of seed were released at most locations by the third week in September. In 1977, 60% to 80% of the total sound seedfall had occurred by the first week in October; whereas, in 1974 and

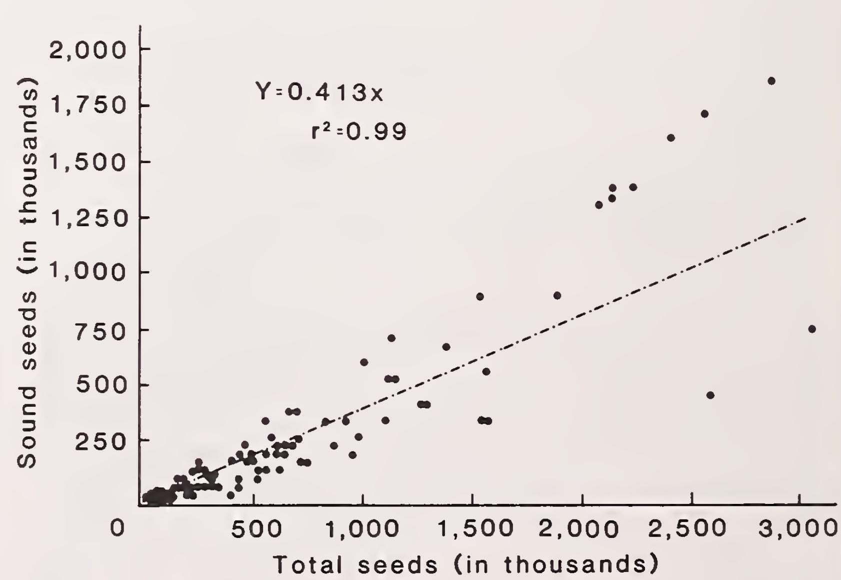

Figure 3.—Periodic average annual sound seedfall in relation to periodic average annual total seedfall.

Table 4.—Percent of total filled seeds released, by collection dates for years of significant seed production when collections could be made in the fall[1]

Plot number	1971 Crop		1972 Crop			1974 Crop			1975 Crop			1977 Crop			1978 Crop		
	Sept. 27-28	June 6-21	Sept. 26-27	Oct. 10-11	June 18-July 3	Sept. 15-19	Oct. 2-3	June 24-July 10	Sept. 17-18	Oct. 6-7	June 9-July 1	Sept. 12-13	Oct. 3-4	June 22-July 12	Sept. 18-25	Oct. 10-11	June 27-July 16
1	40	60	60	7	33	12	41	46	3	42	55	9	55	36	45	16	39
2	53	47	43	28	29	9	31	60	6	36	58	6	65	29	60	6	34
3	65	35	10	32	58	16	12	72	13	4	83	1	60	39	36	36	28
4	63	37	9	48	43	0	26	74	16	15	69	1	66	33	40	13	47
5	55	45	4	40	56	0	29	71	17	6	77	1	65	34	50	0	50
6	49	51	23	22	55	0	45	55	4	25	71	9	71	20	40	20	40
7	44	56	34	27	39	3	40	57	15	12	73	1	71	28	46	23	31
8	32	68	38	22	40	16	21	63	25	16	59	6	69	25	44	22	34
9	42	58	41	21	38	4	39	57	6	15	79	4	68	28	48	32	20
10	47	53	41	28	31	25	36	39	12	38	50	8	60	32	27	33	40
11	38	62	23	23	54	20	32	48	8	20	72	15	57	27	58	17	25
12	64	36	7	29	64	16	23	61	8	37	55	1	59	40	67	22	11
13	68	32	42	19	39	29	32	39	9	31	60	12	61	27	56	11	33

[1]*No collections were made in the fall of 1970 because of early snowfall. Collections were made in the fall of 1973, 1976 and 1978, but seed production was insignificant in those years.*

1975, 39% to 83% of the sound seedfall occurred after the last fall collection was made in early October.

Relation of Seed Production to Stand and Tree Characteristics

Regression analyses of seed production and stand inventory variables resulted in the following equations:

$$\ln(Y+1) = 9.75 - 0.032X_1 + 1.03\ln(X_2+1) \qquad (2)$$

$R^2 = 0.77$, $S_{y \cdot x} = 67{,}500$ (approximated from the untransformed residuals)

where

Y = Average annual sound spruce seed production per acre

X_1 = Average percent of live crown of dominant and codominant spruces

X_2 = Basal area of dominant and codominant spruces per acre.

$$\ln(Y+1) = 12.39 + 0.018\,X_1 - \frac{97.33}{X_2+1} \qquad (3)$$

$R^2 = 0.77$, $S_{y \cdot x} = 62{,}600$ (approximated from the untransformed residuals)

where

Y = Average annual sound spruce seed production per acre

X_1 = Average height of dominant and codominant spruces

X_2 = Average number of stems of dominant and codominant spruces per acre.

Both equations account for 77% of the total variation in the annual average seed production for the 10-year period. The addition of other variables did not significantly improve the precision of either estimate.

The average annual seed production was used as the dependent variable because there was no way to account for annual variation. Furthermore, the independent variables did not change significantly from year to year.

The precision of these equations is about the best that can be expected for estimating periodic annual spruce seed production. However, the coefficients in these equations are likely to change over time. The 10-year mean seed production changed substantially from the 5-year mean because of the 1977 seed crop (Alexander and Noble 1976). While seed production during the period of observation was better than previous work had indicated, and the present study will be continued to provide more data, it is not likely that the amount of variation accounted for or the standard errors of estimate will be improved.

Conclusions

Equations 2 and 3 are useful for estimating potential periodic annual spruce seed production in stands with different characteristics, but the standard errors of estimate approximated from the untransformed residuals are very high. Therefore, the resolution between poor to heavy seed crops is not very good. These equations also do not provide the means for estimating the seed crop rating for any individual year. In some years, seed crops will be total failures, and, even in years of good overall seed production, not all locations will produce good to bumper seed crops. Managers need a method of estimating seed crops from cone counts or some other visual means of estimating potential seed crops on a year to year basis.

In stands to be cut under selection or shelterwood methods, full- and long-crowned dominants and codominants should be retained as leave trees. These trees not only produce the most seed but are also the most windfirm—an important consideration in partial cutting of high-elevation spruce forests. If trees are marked during a good seed year, it is possible to select the dominants and codominants with the largest number of cones. In years when seed crops are poor, old cones on the ground usually indicate which trees are likely to be the best seed producers.

Guidelines developed for partial cutting in old-growth spruce forests (Alexander 1973) require more leave trees because of wind risk than are needed for seed production. Furthermore, windfall susceptibility of trees and stands is more important than spacing of trees for seed production. If the leave trees blow down, there is no seed source.

In managed stands, the number of trees left at the time of the seed cut under a shelterwood method will vary from 20 to 45 dominants and codominants per acre, depending upon the number of entries, length of rotation, and site productivity for those growing stock levels that maximize timber production (Alexander and Edminster 1980). This should be an adequate seed source for natural regeneration if seedbeds are properly prepared and environmental conditions are favorable, but adequate restocking may require more than one good or better seed year when fewer seed trees are left.

This study will be continued to provide more information on (1) the quantity of seed produced and frequency of good to heavy seed crops, and (2) the relationship of filled seed production to stand, tree, and crown parameters. Other investigations will include the effect of cone insects on seed production and the development of a rating system to estimate seed crops from cone counts.

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